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The capture/retention investigation of a gross pollutant trap

J.T. Madhani and R.J. Brown

School of Engineering Systems
Queensland University of Technology, Queensland 4001, Australia

Abstract

A technique was developed to investigate the capture/retention characteristic of a gross pollutant trap (GPT) with fully and partially blocked internal screens. Custom modified spheres of variable density filled with liquid were released into the GPT inlet and monitored at the outlet. The outlet data shows that the capture/retention performances of a GPT with fully blocked screens deteriorate rapidly. During higher flow rates, screen blockages below 68% approach maximum efficiency. At lower flow rates, the high performance trend is reversed and the variation in behaviour of pollutants with different densities becomes more noticeable. Additional experiments with a second upstream inlet configured GPT showed an improved capture/retention performance. It was also noted that the bypass allows the incoming pollutants to escape when the GPT is blocked. This useful feature prevents upstream blockages between cleaning intervals.

Introduction

Gross pollutants are visible waste such as litter and organic matter. Gross pollutants in stormwater collected on the urban runoff path are harmful to the aquatic and terrestrial ecosystem [5]. Gross pollutant traps (GPTs) use internal retaining screens to trap pollutants dimensionally greater than 5 mm prior to the release of stormwater into natural waterways. A recently developed dry linear screening GPT, the LitterBank (C-M Concrete Pty Ltd.), is shown in figure 1 and a plan view with the internal sections is depicted in figure 2. To avoid problems of waste biodegradation and the release of toxic substances, this GPT is designed to be dry.

Figure 1. GPT – LitterBank in situ.

Dry GPTs have received little scientific investigation, unlike water retaining devices such as the hydrodynamic separator. To investigate the capture/retention characteristics of these devices, experiments have been conducted using mostly real floating litter items [8] and artificial pollutants. Artificial pollutants were chosen for their settling velocities; often, a single type was used for simulating sediment [4, 9, 10]. The use of plastic pollutants with different densities has been briefly mentioned elsewhere but no details were given [1].

Previous work [6] on a dry GPT (LitterBank) was solely based on the hydrodynamic performance of the device. Flow features that mobilise and retain gross pollutants have been identified, such as areas of high and low velocities and regions of recirculation. Research was extended to further capture and analyse the pollutant-free flow domain in the GPT for a range of operating and blocked screen conditions [7]. These screen conditions were modelled on findings from field investigations. The investigations showed that internal screens in GPTs are often blocked with organic matter which can radically change the hydrodynamic and, in turn, the capturing characteristics of the device.

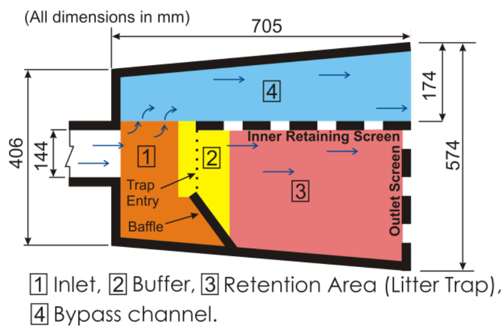

Figure 2. Plan view of gross pollutant trap—LitterBank—with labelled sections.

For the current experiment a technique has been developed to investigate the gross pollutant capture/retention characteristic of a GPT using artificial pollutants. The custom modified artificial pollutants are large, generic, spherical particles (spheres) filled with liquids to emulate gross pollutants that are floatable, partially buoyant, neutrally buoyant and sinkable. The spheres were released upstream of the channel-inlet-configured GPT either continuously or at intervals, and were monitored at the outlet. Details of the experimental method are presented below. Overall, the method was found to be useful and effective in assessing the GPT's capture/retention capabilities.

Experimental method

The experimental rig (50% scale model) was placed in a square section flume (19 m long, 0.6 m wide and 0.6 m deep) at the QUT hydraulic laboratory. Inside the flume, flow into the GPT was through an upstream channel inlet configuration with its height extended to the full depth of the experimental model and with a width of 144 mm (See plan view in figure 2). Experiments were also conducted with an upstream inlet pipe with a 100 mm circular cross section and terminating in a small invert level of 40 mm at the inlet (figure 1). Both these GPT inlet configurations are commonly used in stormwater applications. A constant flow rate was established through the GPT inlets via controller settings on the centrifugal pumps, which circulated the water from underground storage tanks into the flume. Flow rate readings were checked with periodical measurements in the collection tank at the flume outlet using a stop-watch.

At the flume outlet, an experimental methodology had been previously developed which used a downstream weir arrangement to control the nature of the flow in the GPT [6, 7]. A matrix of investigated flow regimes is shown in table 1. The lower flow regimes—1.3 L/s and 3.9 L/s—were set with corresponding weir heights of 0.1 m and 0.3 m above and at the end of the flume terminus raceway. At the higher flows regimes, the weir height was set at the floor level of the raceway (zero). Some variations in these flow conditions (± 10%) during experiments were unavoidable since the constant head tank was not fitted to the flume. For further details on the experimental setup see Madhani et al. [6, 7] which also describes the modelling of blocked screens (table 2).

Run	Flow regime	Weir height (m)	Inlet velocity (m/s)	Flow rate (L/s)	Water depth (m)
1	Low	0.108	0.09	1.3	0.1
2	↑	0.286	0.09	3.9	0.3
3	↓	0	0.39	6.1	0.1
4	High	0	2.14	35.4	0.3

Table 1. Matrix of flow regimes used in the experimental setup for litter capture.

Material	Screen Blockages (%)
Perspex (solid internal walls)	100
Perforated screens (3 mm holes)	68
5 mm rectangular screen mesh	33

Table 2. Material used in placed of normal screens in the GPT to represent percentage of blocked screens

To model fully blocked screens, normal GPT screens were replaced with Perspex solid walls (See table 2). Perforated walls with 3 mm circular and 5 mm rectangular holes were used to model 68% and 33% screen blockages, respectively (table 2). The screen blockage percentages were based on the amount of material obstructing the flow path; no screens represented 0% blockage.

Gross pollutant capture/retention experiments

Generic and custom modified large (≈ 40 mm) celluloid spheres (table tennis balls) were used to model gross pollutants with four different relative densities (See RD in table 3). These densities were chosen to represent the hydrodynamic characteristics of positive, neutral and negative buoyant gross pollutant particles; each density batch consisted of 300 spheres. Preliminary experiments indicated that 300 spheres were sufficient to fill the retention area of the GPT. The spheres were used in the gross pollutant capture/retention experiments for the established flow regimes (table 1) and the three different screen blockages. However, experiments with the upstream circular pipe inlet configuration were restricted to two of the four flow regimes due to time constraints (Runs 1 and 3 in table 1). The preparation of the spheres for these experiments was lengthy (≈ 200 hours) and was performed under strictly controlled procedures to minimise measurement error.

Procedures to measure the physical properties of the spheres (table tennis balls) both empty and filled with water have been documented [2]. A similar method was followed in the current experiment and each sphere was numbered, repeatedly measured and filled to its correct weight for the desired densities, to an estimated error of ± 2%. The external diameter was measured to ± 0.01 mm and weighed to within ± 0.001g. To fill the spheres to the required density, two types of syringes were used (30 cc and 5cc), the larger for the initial filling and the smaller to allow finer density/weight adjustments. The holes were sealed with a waterproofed sealant, an epoxy resin for the heavier particles and a silicon based substance for the lighter spheres. After the sealant had set, the spheres were kept under moisture in a container to avoid swelling and shrinking.

Description	Relative Density (RD)	Physical properties
Floatable	0.10	empty
Partially buoyant	0.90	Filled with tap water
Neutrally buoyant	1.00	Filled with tap water
Sinkable	1.10	Filled with salt water

Table 3. Generic spherical particles used in the litter capture experiments.

Janosi et al [3] reported the swelling and shrinking of celluloid skin when in contact with water or a dry atmosphere. To minimise these effects, the physical properties of the spheres were randomly monitored prior to commencing the experiments. Also, at the net collection point, the spheres were inspected for damage after each experiment.

Downstream of the GPT experimental rig, a net was installed prior to the flume terminus raceway to prevent the spheres from escaping. To monitor and capture the motions of these spheres, a digital video camera (Panasonic SDR-H280) was mounted on a tripod above the experimental rig and connected to a computer via a USB port. Microsoft Window Movie Maker Version 5 was used to record and analyse the motions of these spheres as they were released into the GPT inlet.

The spheres were released upstream of the GPT inlet, either continuously or intermittently. In the continuous mode, a temporary mesh screen placed upstream of the GPT inlet was lifted to release all the spheres simultaneously. For the intermittent feed, small batches (3 or 5) of the spheres were timely introduced into the inlet. At lower flows, a longer interval was selected to avoid the spheres from colliding between successive feedings. Overall, 106 experimental runs were performed. An Excel spreadsheet template was constructed to analyse these runs by obtaining the output time series of the spheres entering and leaving the GPT. The GPT capture/retention efficiencies and the RTD were evaluated from the output data.

Capture/retention efficiency

The time series data from the capture/ retention experiments relate to the number of pollutants captured/retained during and after feeding. The retention efficiency (R') is expressed as:

$$R' = \frac{Total\ -\ escaped}{Total}. \qquad (1)$$

Results and discussion

Earlier investigations [6, 7] revealed that a GPT with fully blocked screens can radically change the hydrodynamic and capture/retention characteristics of a GPT. This can lead to large recirculating flow patterns within the GPT, accompanied by hydraulic short circuiting where the preferred outflow path is via the bypass channel (figure 2). A visual snapshot showed the neutrally buoyant spheres escaping via the outflow path upon entry into the channel inlet GPT (figure 3). Here, a large number of spheres entered the inlet within a very short time. The snapshot in figure 3 revealed the poor capture/retention performance, since the majority of the spheres escaped the GPT. The data point (RD = 1.0, 1.3 L/s) for this snapshot is graphically represented by A, in figure 4. Overall, the capture/retention versus flow rate plots indicate poor performance for experiments with fully blocked screens (figure 4). These plots highlight the capture/retention trends of the variable density spheres (RD = 0.1, 0.9, 1.0 and 1.1); 1.0 on the vertical axis represents 100%.

The total average capture/retention for these experiments was 4%. Below this average, the sinkable and neutrally buoyant spheres (RD = 1.0 and 1.1) appear to be the worst performers. It is unclear whether the high shear velocity gradients causing the flow separation feature next to the inner wall (See B, figure 3) contribute to this poor behaviour. Flow separation was caused by the turning motion of the deflected entry jet into the bypass and peaks nearer the GPT floor [6]. Here, the high shear velocities were seen to force the spheres to escape into the bypass. This feature was not prominent in lower screen blockages.

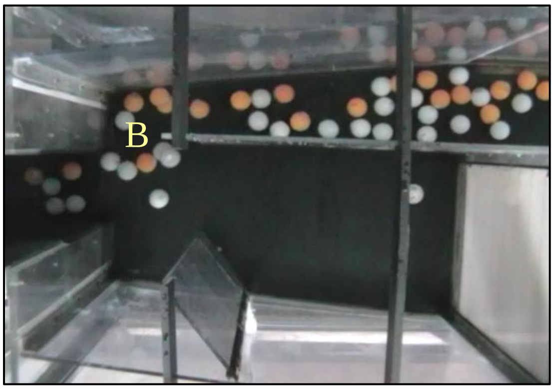

Figure 3. Left, experiments with fully blocked screen show the neutrally buoyant spheres (RD =1.0) escaping the GPT via the bypass (See data point A in figure 4 at 1.3 L/s on the abscissa—see table 1). B (See left of figure) denotes the existence of large negative horizontal velocities (right to left).

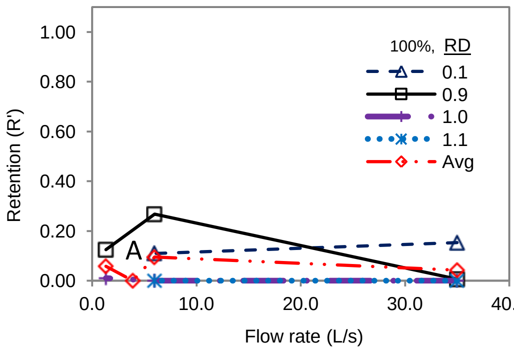

Figure 4. Normalised capture/retention profiles (R') for continuously fed variable density spheres (RD) = 0.1, 0.9, 1.0 and 1.1. The channel inlet configured GPT experiment is with fully blocked screens tested under varying flow rates (See table 1). A (See left of figure) denotes poor capture/retention performance which may be attribute to large negative velocities denoted by B in figure 3.

To investigate the lower screen blockages (33% and 68%), the solid internal walls were replaced with perforated screens in the GPT (table 2). The GPT's performance dramatically improved with these blockages, particularly at higher flow rates where the entry jet transported the spheres further into the retention area of the trap (figure 5). Although the capture/retention trends were similar in both cases, the 68% blocked screen performed slightly better at the higher flow rate (figure 6). For the sake of brevity, figure 6 shows only the capture/retention trends for this case. This finding is of practical significance for the maintenance of the GPT since the device can operate efficiently with at least 68% of the screens blocked.

At lower flow rates the high performance trends were reversed, particularly for the heaviest spheres (RD = 1.1) which rolled along the GPT floor. Hence, this setback reduced the average performance trends of the 33% and 68% blocked screen cases to 46% and 57%, respectively (table 4). A noticeable feature is that the performance trends of the lighter spheres was better in the lower flow regime with a shallower water depth (Run 1, table 1), despite the same inlet velocities. Furthermore, at lower flow regimes (< 6 L/s), the capture/retention characteristics of spheres with different densities tended to vary. The varied capture/retention characteristics between the higher and lower regimes also tended to influence the deposition patterns of the spheres (figures 5 and 7).

Screen blockage (%)	Retention eff. (%)	
	Inlet configuration	
	channel	pipe
33	46	76
68	57	83
100	6	1

Table 4. The average capture/retention efficiencies for the three blockage conditions and both the continuous and intermittent methods of input.

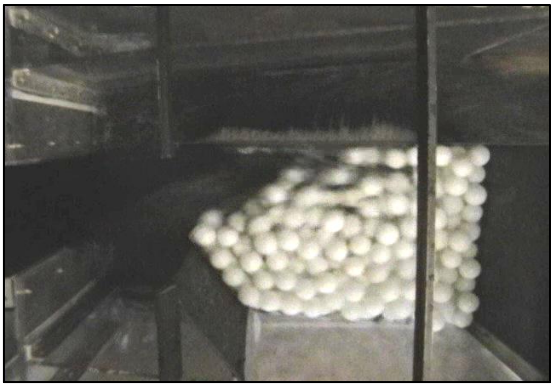

Figure 5. Deposition pattern for the GPT with 68% blocked screen shows total (100%) capture/ retention of the lightest pollutants (RD = 0.1) at a high (35 L/s—Table 1) flow rate (See C, figure 6).

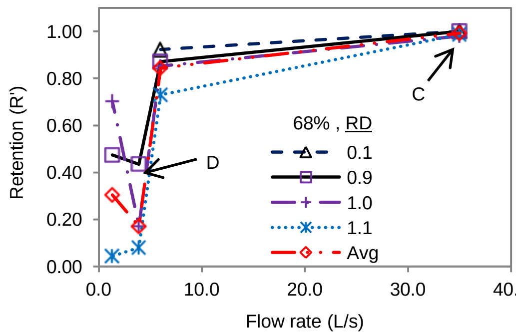

Figure 6. Normalised capture/retention profiles (R') for continuously fed variable density spheres (RD) = 0.1, 0.9, 1.0 and 1.1. The channel-inlet-configured GPT experiment is with 68% blocked screens tested under varying flow rates (table 1). See snapshots of capture/retention performances in figures 5 and 7 for C and D, respectively.

In the higher flow regimes, the retained spheres were stacked in layers (figure 5). Otherwise, at low flow rates, the motion of the spheres was sufficiently slow for them to form queues, resulting in a single layer deposition inside the GPT (figure 7).

Further comparisons showed similarities in deposition patterns of an infield GPT operating intermittently between rain events (figure 8). This GPT had a circular pipe inlet, and a similar model was partially tested in the laboratory. The model entered above the GPT floor with a small invert level and was partially tested using two flow regimes (See Runs 1 and 3, table 1). The invert provided the incoming gross pollutants with extra momentum which improved the GPT's performance during low flows.

The average results of the circular pipe and channel inlet configured GPT are summarised in tables 4 and 5. These results show clearly that overall, the raised inlet—circular pipe—had better gross pollutant capture/retention efficiencies for 33% and 68% blocked screens. Also, the variable density gross pollutants performed better for this inlet.

Artificial pollutants (spheres) RD	Retention eff. (%)	
	Inlet configuration	
	channel	pipe
0.1	34	48
0.9	49	56
1.0	43	55

Table 5. The average capture/retention efficiencies for the four spheres with different densities using the step input function (continuous feed).

Figure 7. Single layer deposition pattern for the GPT with 68% blocked screen capture/retention of the lightest pollutants (RD = 0.9) at a low (3.9 L/s) flow rate (See D, figure 6).

Figure 8. A snapshot of a field investigated GPT showing deposits of sediments which are similar to the pattern from the gross pollutant capture/retention experiments with partially buoyant spheres (See figure 7). Note the blocked inlets in both cases.

Conclusions

A technique was developed to assess the retention/capture characteristics of a GPT with fully and partially blocked screens. This technique facilitated a rigorous GPT assessment and can be used on other treatment devices. The mainly experimental technique used custom modified spheres with variable densities to represent floatable, partially buoyant, neutrally buoyant and sinkable gross pollutants in the capture/retention experiments. The spheres were released into the GPT inlet, while the outlet was monitored with time. The experiments consisted of a range of flow regimes, two different inlet designs, and different screen blockage conditions. The outlet data was used to assess the GPT's performance and to investigate the capture/retention characteristics of the variable ball densities.

The main findings reveal that the retention/capture characteristics rapidly deteriorate when the internal screens are fully blocked. However, below 68% screen blockage, the GPT's performance improves dramatically, particularly at higher flow rates. The practical significance of this finding is important for GPT maintenance which can be scheduled when this level of blockage is reached.

During lower flow rates, the performance trends were reversed. Also, a raised inlet GPT offered greater capture/retention capabilities. Experiments with this inlet showed that spheres of variable density have similar retention/capture characteristics.

The technique developed and examined here, demonstrates the usefulness and effectiveness of describing the gross pollutant capture/retention capabilities of a GPT under various operating conditions. This technique is also capable of highlighting possible GPT inlet improvements and positive design features such as the bypass channel.

Acknowledgments

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